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Priroda, August 1959

A POSSIBLE MECHANISM FOR CREATION OF "A TERRESTRIAL CORPUSCULAR RADIATION" UNDER INFLUENCE OF COSMIC RAYS

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Translated by Joseph L. Zygielbaum

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Part I

Scientific Information

TERRESTRIAL CORPUSCULAR RADIATION

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Priroda, August 1959

Translated by Joseph L. Zygielbaum

The launching of artificial Earth satellites and cosmic rockets has opened entirely new possibilities in the investigation of cosmic space. Scientific investigations using satellites and rockets which were conducted up to the present time have led to the interesting and unexpected discovery of two zones of high intensity charged particles, which are located at a distance of thousands and ten thousands km from the surface of the Earth.

The factor determining the existence of these zones, reproduced in Fig. 1, is the magnetic field of the Earth. If a charged particle of not too high energy falls into the magnetic field of the Earth, (which represents in itself at first approach a dipole field), this particle, which possesses a certain initial velocity, will begin to travel through the magnetic field along a spiral down a force-line. The preservation of the magnetic moment of the particle leads to its movement along a force-line according to the law $\sin^2 \theta/H = \text{const}$, where θ is the angle between the vector velocity of the particle and the vector of intensity of the magnetic field H at the given point of the trajectory. During the movement of the

particle along a magnetic force-line it reaches a region of large geomagnetic latitudes, at the same time approaching the Earth. The intensity H of the magnetic field of the Earth then increases and since $\sin^2 \theta$ is a limited value, a deflection of particles takes place, and the particle begins its movement in the opposite direction along the same force-line.

Thus the magnetic field of the Earth becomes a unique trap for the charged particles. After falling into the trap, the particle begins to travel over closed trajectories. This makes it possible, by a comparatively small intensity of injection of the particles into the trap, to obtain a high density of energy inside. In principle, this process is now utilized by physicists in laboratory experiments on controlled thermo-nuclear reactions.

The intensity of particle fluxes inside the trap is determined by the force of injection and the life span of the particle. Regardless of how low the atmospheric density is at large altitudes, the magnetic moment of the particle cannot remain constant due to energy losses during collisions. Therefore the charged particle, after falling into the magnetic trap, is subjected to a very high but limited number of oscillations. The number of oscillations of the particle in the magnetic trap can be limited by the interaction of the particle with the atmospheric matter, and other causes, e.g.: the nonstability of the magnetic field, and the possible existence of electrical fields. At the present time it is very difficult to consider the influence of all real factors on the life span of a particle in the magnetic field of the Earth.

However there is no doubt that high intensity zones which were discovered with the help of satellites and cosmic rockets represent fluxes of charged

particles which were trapped by the magnetic field of the Earth. The fact that these fluxes are concentrated in a limited area of space supports this premise. S. N. Vernov has named this phenomenon the "Terrestrial Corpuscular Radiation".

Since movement in the magnetic field takes place along force-lines, the structure of the zones of terrestrial corpuscular radiation should be determined by the magnetic field of the Earth; the zones of high intensity especially should have their boundaries marked by the force-lines of the magnetic field.

The fact that in the magnetic field of the Earth both external and internal zones of terrestrial corpuscular radiation were formed, is obviously related to the existence of several varying mechanisms of injection of particles.

The first experimental indications of the existence of high intensity charged particles at large altitudes was obtained by Dr. Van Allen during the flights of the American satellite Alpha and Gamma. We now understand that the great intensity which was observed during these experiments was related to the fact that the satellites penetrated the internal zone.

The first data about the existence of two zones were obtained with the aid of the third Soviet artificial Earth satellite. The instruments which were installed on this satellite have recorded an increase in the count tempo and ionization during the flight of the satellite to the north ~ 550 deg of northern latitude and to the south ~ 55 deg of southern latitude. The flight altitude of the satellite in the northern hemisphere in the zone of increased ionization varied from ~ 250 km to 550 km, and in the southern hemisphere it equalled ~ 1, 600 km.

The systematic increase of ionization in these regions is caused by the the satellites crossing the lower boundaries of the internal zone. Since the

internal boundaries of this zone near the surface of the Earth are limited by the geomagnetic parallels ~ 55 deg, then in the equatorial plane the internal boundaries of the external zone are at a distance of 20,000 km from the center of the Earth.

With the aid of instruments which were installed on the third Soviet satellite a systematic increase of ionization was also discovered during the satellite's flight over the equatorial region. In Fig. 2 samples of recordings made by a scintillation counter aboard the diesel electric vessel "Ob" in the vicinity of South America are reproduced. As can be seen, during the satellite's northerly flight ~ 45 deg of southern latitude, ~ 35 deg of geomagnetic southern latitude, the ionization in a crystal was 10^{12} to 10^{13} ev/sec at an altitude between 800 to 1,100 km and ~ 1,800 km. During the flight of the satellite in the direction of the southern pole southerly ~ 55 deg of southern latitude, the ionization in the crystal decreased at first to ~ 10^{10} ev/sec, then an increase followed, which is related to the satellite's penetration of the external zone of high intensity during its further flight. Numerous recordings show that the external zone and the equatorial or internal zone of high intensity are separated from each other by an area in which the intensity of particles is considerably less than inside of each zone.

From data obtained with the aid of the third Soviet satellite, it follows that the external boundaries of the internal zone pass along magnetic force lines, which cross the surface of the Earth at the geomagnetic latitude ~ 40 deg. This means that the external boundaries of the internal zone in the equatorial plane depart at a distance of 10 to 15,000 km from the center of the Earth.

Recordings of instrument readings from the third satellite which were utilized during the processing correspond to a sufficiently narrow interval of longitude in the trajectory of the satellite's flight in the vicinity of South America. A noticeable dependence of intensity in the equatorial region on longitudes within the range of 35 to 85 deg of western longitude was not discovered.

As a result of the study of the dependence of energy emanation in mean latitudes on the longitude of the satellite's crossing the equator, it was established that the maximum intensity in the equatorial zone was observed in the region of South America and the minimum above Australia. The direct measurements of Dr. Van Allen, accomplished with an American satellite 1958 Epsilon, confirmed this. According to data from this satellite, the lower boundaries of the equatorial zone are located at an altitude ~ 500 km in the western hemisphere and at an altitude ~ 1500 km in the eastern hemisphere.

The discovered dependence of the altitude of the lower equatorial zone limits on the longitude might be explained by a displacement of the magnetic dipole, in relation to the center of the Earth, to a magnitude ~ 500 km.

The study of the terrestrial corpuscular radiation may further yield important information about the magnetic field of the Earth at high altitudes. Also of interest is the explanation of the nature and energetic spectrum of particles which are caught in the magnetic trap. The investigation of this problem is necessary for the explanation of the mechanism of injection.

Data from the third artificial Earth satellite have indicated the existence of protons with an energy of ~ 100 mev in the internal zone. The flux of these particles consists of ~ 100 particles/cm^2/sec sterad. On the other hand,

according to data from the American satellite Epsilon, it is possible to draw a conclusion about the presence of a soft radiation in the equatorial zone. If the nature of this soft radiation is unknown at the present time, the proton components are most probably created because of the disintegration of neutrons, which are generated in the Earth's atmosphere under the influence of cosmic rays. The neutron mechanism of injection of charged particles into the Earth's magnetic field was proposed by S. N. Vernov and A. I. Lebedinsky.

According to data from the third Earth satellite, the proton fluxes in the internal zone possess a high stability, as should be expected, if we consider the neutron hypotheses of injection. Actually, the source of injection is constant in time, and in order to explain the observed intensity, the life period of a particle in the magnetic flux over a period of one year is required.

Obviously, an entirely different mechanism of injection is responsible for the creation of the external zone. From data from the third Soviet satellite, it became known that the radiation of the external zone consists of electrons with an energy $\sim$ 100 kev. It was discovered that a number of these electrons is subjected to great fluctuations. More detailed data about the external zone were obtained through the help of the Soviet cosmic rocket (Lunik I), the flight trajectory of which in the geomagnetic coordinates is reproduced by the curve I in Fig. 1. A complete energy emanation in a crystal with the dimensions of $40 \times 40 \times 40$ mm^3, which was measured by a scintillation counter and screened from the external space by an aluminum cover with a thickness of $\sim$ 1g/cm^2, is presented by the curve I in Fig. 3. As can be seen from Fig. 3, intensity of

particles of the external zone depends strongly on distance, and has a maximum at an altitude of 26,000 km from the center of the Earth.

The results of intensity measurements of particles of the external zone, which was made by the Soviet cosmic rocket, can be compared with data which was obtained by the American rocket "PIONEER III". The flight trajectory of this rocket during its departure from the Earth is shown by the curve II, and during its approach to the Earth by the curve III in Fig. 1. In Fig. 3 the curves II and III represent the count tempo of the Geiger counter, which was installed on the American rocket. The effective area of the counter equals 0.75 cm^2. The counter was shielded from the external space by a layer of metal $\sim$ 1 g/cm^2.

As can be seen from the comparison of the curve I with the curves II and III, the maximum intensities which were fixed by the Soviet and American rockets are located at somewhat varying distances. Such a position of intensity maximums may be explained by several reasons, including the variation of spectro-sensitivity of the instruments. It should also be taken into consideration that the flight of the rockets took place at different times and the intensity maximums of the rockets' instruments were fixed at different hemispheres.

For the curves I to III the presence of a minimum (curves II, III) or plateau (curve I) of distances from 10 to 15,000 km is characteristic. This characteristic of the curves is explained by the fact that the flight trajectory of distances from 10 to 15,000 km exceeded the limits of the external zone or approached its boundaries.

The instrumentation which was installed on the Soviet rockets consisted of several detectors with variable spectro-sensitivity including two scintillation

counters, which measured the number of particles of various energies and a complete energy emanation in a crystal under different thicknesses.

The instruments of the Soviet rocket have confirmed the presence of electrons with an energy of 20 to 100 kev in the external zone and have proven that a spectrum of charged particles does not remain constant at different distances. Inside the external zone the spectrum of particles becomes most soft: the value of effective energy in the maximum of intensity is ~ 25 kev, at the time when at the edges of the zone, this magnitude is ~ 50 kev. The instruments of the Soviet cosmic rocket have not disclosed any noticeable number of high energy particles in the external zone.

Thus, with the help of satellites and cosmic rockets, the existence of two zones of terrestrial corpuscular radiation was discovered, which differ in space location and in particle contents. It is supposed that the internal and external zones also differ in origin. If the internal zone exists because of the neutron mechanism of injection, the external zone is created because of the penetration into the Earth's magnetic field of particle fluxes which were emanated by the Sun.

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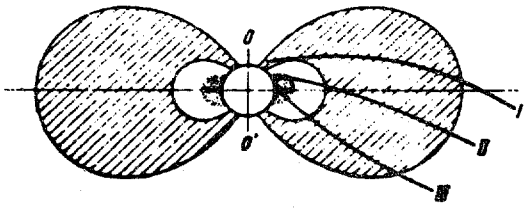

Fig. 1. Diagram of Terrestrial Corpuscular Radiation. Dots indicate internal zone, dash lines indicate the external zone; OO' is the Earth's geomagnetic axis; I, II, III are the trajectories of cosmic rockets.

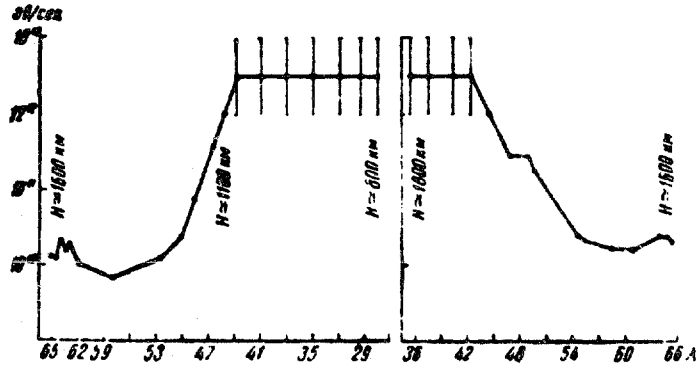

Fig. 2. Samples of Recorded Readings of Luminescent Counter, Taken in the Southern Hemisphere on June 12, 1958. The abscissa axis shows the geographical latitude (southern), and the ordinate axis - the energy emanation in a crystal according to dinode current measurements.

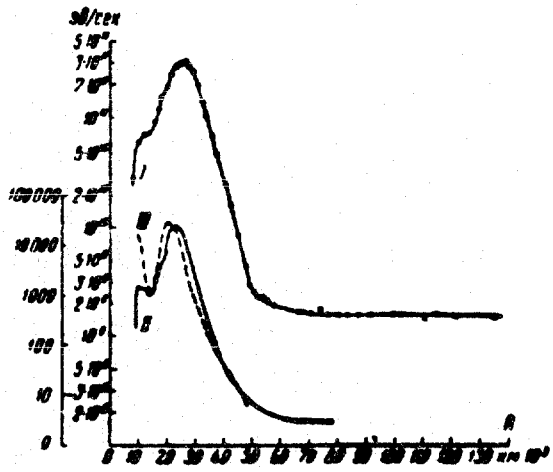

Fig. 3. Dependence of Intensity on Flight Altitude. R is the distance to the center of Earth. I - is the total energy emanation in a crystal according to data from the Soviet cosmic rocket; II, III are the count tempos according to data from the American rocket "Pioneer III". (II - at departure from Earth; III - at approach to Earth).

Part II

A POSSIBLE MECHANISM FOR CREATION OF "A TERRESTRIAL CORPUSCULAR RADIATION" UNDER INFLUENCE OF COSMIC RAYS

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The expression "Terrestrial Corpuscular Radiation" can be interpreted as a flux of charged particles, which travel along closed trajectories in the Earth's magnetic field. We think that the following mechanism of radiation origination is most worthy of attention.* Under the influence of cosmic rays the Earth, as well as any other heavenly body, becomes a source of neutrons. Since there is no electrical charge, the neutrons penetrate unobstructed through the magnetic field at large distances from the Earth. The charged particles which were created through the disintegration of neutrons will travel through the magnetic field of the Earth along the force-lines. In time these particles will fall into a

*Calculations which were based on this mechanism, were explained by us at the seminar of the Physical Institute of the Academy of Sciences USSR on June 6, 1959 and at the session of the Assembly of the International Geophysical Year on June 31, 1958.

region of high geomagnetic latitudes, where the field quickly increases with the increase in latitude. In this region, as the particle approaches the Earth, the vector of its velocity will turn in respect to the vector $\vec{H}$, until the angle between the velocity of the particle and the vector $\vec{H}$ in the latitude of λ_{max} will become equal to 90 deg. At this point the particle will "turn" and will return along the same magnetic force-line.

At high altitudes ($\sim 10^3$ - 3×10^3 km) the atmospheric density is very low, and during one oscillation between the northern and southern turning points, a particle passes a negligible number of particles of matter $\sim 10^{-8}$ to 10^{-10} gm/cm^2 and due to ionization loses its energy 10^{-2} to 10^{-4} electron volts. Therefore, the disintegration products of neutrons, which possess energies of $\sim$ 1 Mev and more, under proper conditions, will be able to accomplish 10^8 magnitude and more oscillations. In connection with this, the intensity of the current of these particles will increase a similar number of times. Experimental data indicates the existence of such a radiation (Ref. 2, 3).

We will investigate in detail which factor determines the intensity of this radiation. In the absence of energy losses and dispersion of particles, its magnetic moment μ will be preserved with very great accuracy. This will lead to the point that the particle will complete k oscillations from one hemisphere to the other, $k \approx (R_0 \rho)^6$, where R_0 is the radius of the Earth, ρ is the radius of the curvature (Ref. 4). The conservation of the magnetic moment of the particle will lead to the fact that its movement will be subjected to the law

$$\sin^2 \theta / H = \text{const}, \qquad (1)$$

where θ is the angle between the vector of velocity and the vector of the magnetic field at the given point of the trajectory. We assume that the magnetic field of the Earth is the field of a dipole. In the equatorial plane we will select a platform, $\sum_0$, the center of which is located at a distance of R_e from the center of the Earth. All particles with a given impulse, p (for which the radius of curvature in the equatorial plane ρ_e is many times less than the linear dimensions of the platform $\sum_0$), will travel inside a tube, the cross-section of which, at the latitude λ, will be $\sum(\lambda)$. We are to assume that a magnetic force-line, which passes through the points h_1, λ_1, will be the axis of the selected "tube". It is obvious that all particles which are created as the result of the disintegration of neutrons inside this tube at its various points will pass through the cross section $\sum(\lambda_1)$ only if at the point of "birth" the particles had such an angle θ between their velocity and the magnetic field that the equatorial plane was crossed by these particles under an angle θ_0, which satisfies the conditions

$$\theta_{0\,\min} \leq \theta_0 \leq \theta_{0\,\max} \tag{2}$$

Here $\theta_{0\,\max}$ is determined from the condition $\lambda_1 = \lambda_{max}$. The maximum latitude λ_{max}, which can be reached by the particle, and which has an angle of θ_0 when $\lambda = 0$, is determined by the equation:

$$\sin^2 \theta_{0\,\max} = \cos^6 \lambda_1 / \sqrt{4 - 3\cos^2 \lambda_1} \tag{3a}$$

$\theta_{0\,\min}$ is determined from the condition $h(\lambda_{max}) = R_e \cos^2 \lambda_{max} - R_0 > 0$:

$$\sin^2 \theta_{0\,\min} = \left(\frac{R_0}{R_0 + h_1}\right)^3 \cos^6 \lambda_1 / \sqrt{4 - 3\frac{R_0}{R_0 + h_1}\cos^2 \lambda_1} \tag{3b}$$

We may assume that in 1 sec such particles originate in the tube $N(\theta_0, R_e, v)d\theta_0$, and they will cross the equatorial plane with angles between θ_0, $\theta_0 + d\theta_0$. To the given angle θ_0 and R_e a determined trajectory of particles with a determined path length $S(\theta_0, R_e)$ corresponds, in addition to a determined energy loss along this path $\Delta E(\theta_0, R_e)$. If a particle possesses an energy of E_0, during its origination it can travel through the entire length of the tube from one turning point to the other $K(\theta_0, R_e) = E_0/\Delta E$. Consequently, the flux of particles which pass the platform $\sum_0$ in 1 sec with angles between θ_0, $\theta_0 + d\theta_0$, is equal to $K(\theta_0, R_e)\, N(\theta_0, R_e, v)\, d\theta_0$. This same flux of particles will cross the platform $\sum(\lambda_1)$ with an angle less than θ_1. Therefore, the global flux of particles which passes through a single sphere at the latitude of λ_1 will be

$$j(\lambda_1, h_1) = \frac{\sqrt{4 - 3\cos^2\lambda_1}}{\cos^6\lambda_1} \int_{\theta_0\,\min}^{\theta_0\,\max} \frac{n(\theta_0, R_e, v)\, K(\theta_0, R_e) d\theta_0}{\cos\theta_1(\theta_0, \lambda_1)}\,; \qquad (4)$$

here $n(\theta_0, R_e, v) = N(\theta_0, R_e, v)/\sum_0$ is the number of particles which are created in 1 sec in the entire tube, which has an area with a cross section of 1 cm^2 on the equator.

We will calculate the number of particles which are created in 1 sec in a tube with a cross section of 1 cm^2 on the equator (see Fig. 1). Let us take for instance, on the latitude λ an element with a circumference of the tube which equals $dv = \sigma dl$, where $\sigma = \cos^6\lambda/\sqrt{4 - 3\cos^2\lambda}$ is the area of cross section of the "tube" and dl is the element of length of the magnetic force-line. If the flux of neutrons equals n_H and they fall on an element with a circumference of dv with

an angle less than ϕ to the platform σ, then in this circumference dv the disintegration of $n_H \sigma dl / \tau_0 v_H$ neutrons will take place each sec (here τ_0 is the life span of a neutron, and v_H is the neutron's velocity). From all products of disintegration which take place in dv, only those should be selected which possess such angles of θ_1, $\theta_1 + d\theta_1$, that these particles on the equator have the angles θ_0, $\theta_0 + d\theta_0$.

Electrons are discharged isotropically during the disintegration of neutrons, and therefore the number of electrons of disintegration which possess angles of θ_1, $\theta_1 + d\theta_1$ will equal

$$n_H(\lambda, R_e) \cos^6 \lambda \frac{d\theta_1}{d\theta_0} \sin \theta, \; d\theta_0 \, dl / \tau_0 \, v_H \sqrt{4 - 3 \cos^2 \lambda} . \qquad (5)$$

In relation to (Ref. 5), it was assumed during calculations, that the neutron flux albedo through a single sphere, at a fixed altitude, is proportional to $\cos^{-5} \lambda$ for $\lambda \leq 50°$.

The full number of electrons of disintegration, which were created in the entire "tube" will equal

$$n_e(\theta_0, R_e) d\theta_0 = R_e \frac{\cos \theta_0 \sin \theta_0 d \theta_0}{\tau_0 \, v_H} \int_{\theta}^{\lambda_{max}} \frac{n_H(\lambda, R_e) \cos^4 \lambda (4 - 3 \cos^2 \lambda)^{1/2}}{\sqrt{\cos^6 \lambda - \sin^2 \theta_0} \sqrt{4 - 3 \cos^2 \lambda}} d\lambda \qquad (6)$$

where λ_{max} satisfies the equation (3), $n_H(\lambda, R_e)$ is the flux of neutrons through a single sphere. Relative to the fact that the protons practically preserve the direction of the neutrons, the number of protons which were created in the circumference dv with angles of θ_1, $\theta_1 + d\theta_1$ will equal

$$n_p(\lambda, R_e, \theta_1)d\theta_1 = n_H(\lambda, R_e, \theta_1)d\theta_1 \frac{\sigma dl}{\tau_0 v_H} \quad (7)$$

The full number of protons in the entire "tube" equals

$$n_p(\theta_0, R_e)d\theta_0 = \frac{R_e \cos\theta_0 \, d\theta_0}{\tau_0 v_H} \int_0^{\lambda_{max}} \frac{n_H(\lambda, R_e, \theta_1) \cos^7\lambda (4 - 3\cos^2\lambda)^{1/4}}{\sqrt{\cos^6\lambda - \sin^2\theta_0}\sqrt{4 - 3\cos^2\lambda}} d\lambda, \quad (8)$$

where $n_H(\lambda, R_e, \theta_1)$ is the flux of neutrons which travel with an angle less than θ_1 towards the vector $\vec{H}$ through a single sphere.

In order to determine the flux of particles of terrestrial corpuscular radiation, it is necessary to know "the factor of accumulation" $K(\theta_0, R_e)$. When the basic reason for energy loss is the ionization loss, $K(\theta_0, R_e)$ equals $z_0/\Delta x(\theta_0, R_e)$. Here z_0 is the traveled distance which corresponds to the energy E_0; Δx is the amount of matter which is passed by a particle between two turning points. There is some basis for the assumption that during the passage of particles through the atmosphere, general losses, including losses caused by collisions of particles with atomic electrons as well as plasma electrons, are comparatively equal to ionization losses.

We will assume that the density of the atmosphere changes with altitude according to the law $\rho = \rho(h)$, and that at the point (R, λ) a particle travels with an angle less than θ towards a force-line. Then, if a particle travels along the path ds, the projection of this path on the magnetic force-line is $dl = ds \cos\theta$; thus:

$$\Delta x = \int \rho ds = 2R_e \int_0^{\lambda_{max}(\theta_0)} \frac{\rho(h) \cos^4 \lambda \sqrt{4 - 3\cos^2 \lambda}}{\sqrt{\cos^6 \lambda - \sin^2 \theta_0} \sqrt{4 - 3\cos^2 \lambda}} d\lambda \quad (9)$$

We have assumed during the calculation of K, that $\rho(h) = \rho_0 e^{-h/Z}$ up to altitudes of h = 3,000 km and $\rho(h)$ = const = 10^2 atoms/cm^3 when h > 3,000 km. The value of ρ_0 is assumed to be equal to 1.4×10^6 atoms/cm^3 at an altitude of 400 km and z = 200 km (Ref. 6).

We have performed calculations of the intensity of the terrestrial corpuscular radiation at various altitudes and latitudes. The results of these calculations are shown in Fig. 2. At distances larger than the ones illustrated in Fig. 2, the intensity should decrease at first by ~ $1/R^2$ when the decrease of particles is determined by the ionization losses, and therefore by ~ $1/R'^3$ when decrease of particles is determined by the escape from the "magnetic traps" which are connected with the nonpreservation of magnetic moment (Ref. 4). The calculations which are based on Ref. 7 show that although the number of disintegrating neutrons near the Earth cosmic ray albedo is very small, it can create an intensive terrestrial corpuscular radiation. A comparison of calculations with experimental data (Ref. 2) shows that the intensity near the equator which was obtained during the experiment is less than the calculated data by ~ 100 times. According to experimental data (Ref. 2), terrestrial corpuscular radiation is absent at geomagnetic latitudes of more than 40 deg, at the time when $j(\lambda = 40°) \sim j(\lambda = 0°)$— a discrepancy of more than 10^5 times.

For experimental purposes, the existence of additional escapes from the "magnetic traps" is assumed, which are especially significant at large latitudes. This might be caused by the presence of electrical fields. This assumption is supported by data on perturbations of the Earth's magnetic field as latitude increases. In other words, we propose that with the increase of latitude, the restrictions of the Stermer theory on the energy of particles are increasingly violated. If this is true, then it is possible for particles with low energy to penetrate toward the Earth at sufficiently large latitudes. From this viewpoint electrons with an energy of ~ 100 kev which were disclosed in the work (Ref. 2), and which always appear when a satellite flies through a latitude of more than 60 deg should be considered as the initial electron component of cosmic rays, which apparently come to us from the Sun.

The mechanism of creation of radiation from the disintegration of neutrons discussed above should take place near astrophysical objects which possess a magnetic field. Therefore, the investigation of this radiation in the vicinity of planets of the solar system may be a means for the discovery of weak magnetic fields. Calculations show that with this method magnetic moments of ~ 1,000 times less than the moment of the Earth can be discovered. It is interesting to note that at sufficiently high altitudes the terrestrial corpuscular radiation will heat up the atmosphere considerably more than the radiation of the Sun.

The authors express their deep gratitude to D. V. Skobeltsyn and M. S. Rabinovitch for their assistance in investigating the problems relating to the effectiveness of the magnetic trap.

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Received November 21, 1958

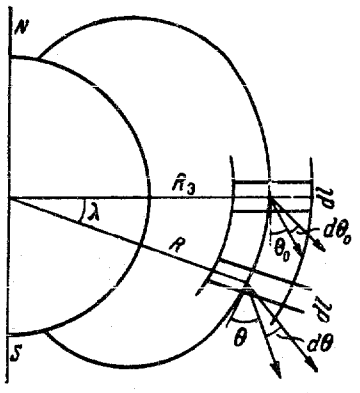

Fig. 1. Diagram Showing Number of Particles Which are Created in 1 sec in a Tube with a Cross-Section of 1 cm^2.

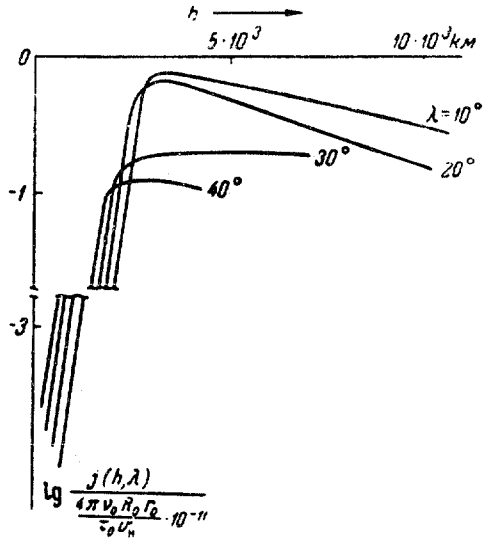

Fig. 2. Altitude Dependence of Terrestrial Corpuscular Radiation j(h, λ) at Various Geomagnetic Latitudes. On the ordinate axis is placed the magnitude, $I(h, \lambda) = j(h, \lambda)/(4\pi\nu_0 R_0 r_0/\tau_0 v_H)$; on the abscissa axis, the altitude h in thousands kilometers. ν_0 is the flux of neutrons which leave the atmosphere at the equator over 1 cm^2; r_0 is the course of ionization of particles in atomic numbers for 1 cm^2.

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